

LENS
Measuring the
Neutrino Luminosity of the Sun

PANIC05 Neutrino Satellite Meeting
October 29, 2005

Christian Grieb
Virginia Tech

LENS-Sol / LENS-Cal Collaboration

(Russia-US: 2004-)

Russia: **INR (Moscow):** I. Barabanov, L. Bezrukov, V. Gurentsov,
 V. Kornoukhov, E. Yanovich;

INR (Troitsk): V. Gavrin et al., A. Kopylov et al.;

U. S.: **BNL:** A. Garnov, R. L. Hahn, M. Yeh;

U. N. Carolina: A. Champagne;

ORNL: J. Blackmon, C. Rascoe, A. Galindo-Uribarri;

Princeton U. : J. Benziger;

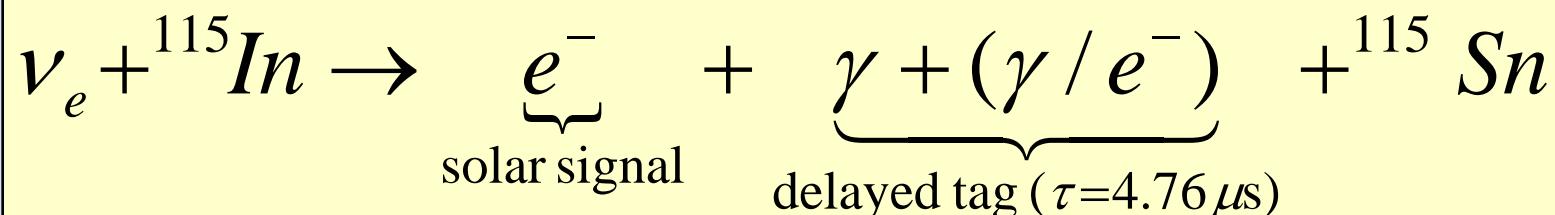
Virginia Tech: Z. Chang, C. Grieb, M. Pitt,
 R.S. Raghavan, R.B. Vogelaar;

LENS-Indium: SCIENCE GOAL

Precision Measurement of the Neutrino Luminosity of the Sun

LENS-Sol:

- Measure the low energy solar ν spectrum (pp, ^7Be , CNO)
- $\pm \sim 3\%$ pp- ν flux
- Experimental tool: Tagged CC Neutrino Capture in Indium



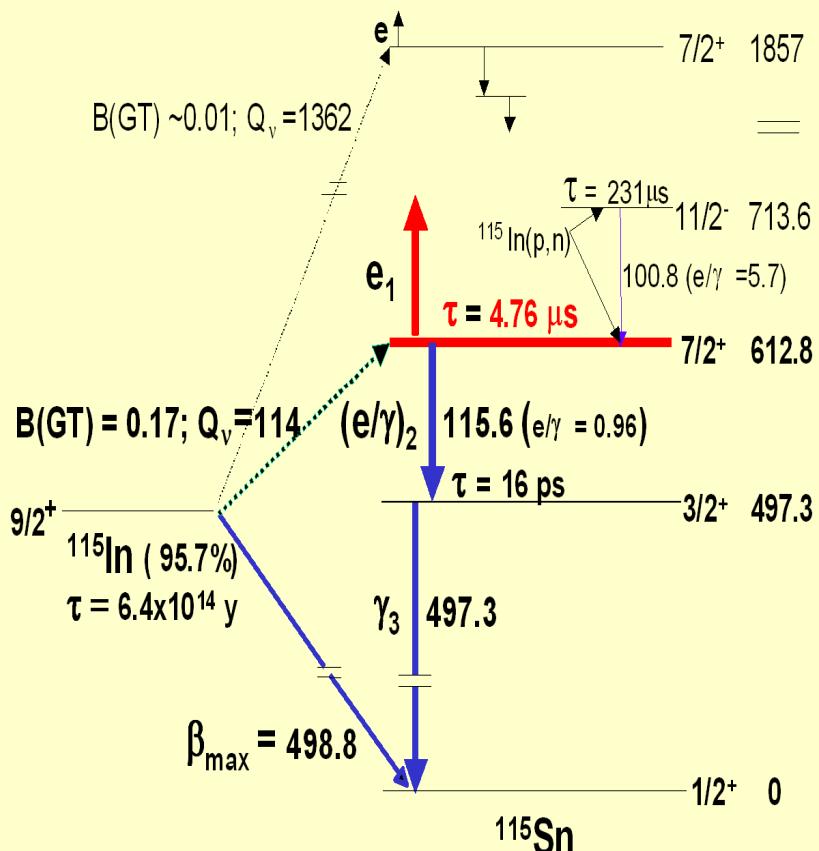
LENS-Cal:

- Measure *precise* B(GT) of ^{115}In CC reaction using MCi ^{51}Cr neutrino source at BAKSAN
- Tagged ν -capture to *specific* level of ^{115}Sn
- **Note:** B(GT) = 0.17 measured via (p,n) reactions

LENS-Indium: Foundations

CC ν -capture in ^{115}In to excited isomeric level in ^{115}Sn

The Indium Low Energy Neutrino Tag



Tag: Delayed emission of $(e/\gamma) + \gamma$

Threshold: $114 \text{ keV} \rightarrow \text{pp-}\nu$'s

^{115}In abundance: $\sim 96\%$

Background Challenge:

- Indium-target is radioactive! ($\tau = 6 \times 10^{14} \text{ y}$)
- ^{115}In β -spectrum overlaps pp- ν signal

Basic background discriminator:

Tag energy: $E_{\nu\text{-tag}} = E_{\beta\text{max}} + 116 \text{ keV}$

*^7Be , CNO & LENS-Cal signals
not affected by Indium-Bgd!*

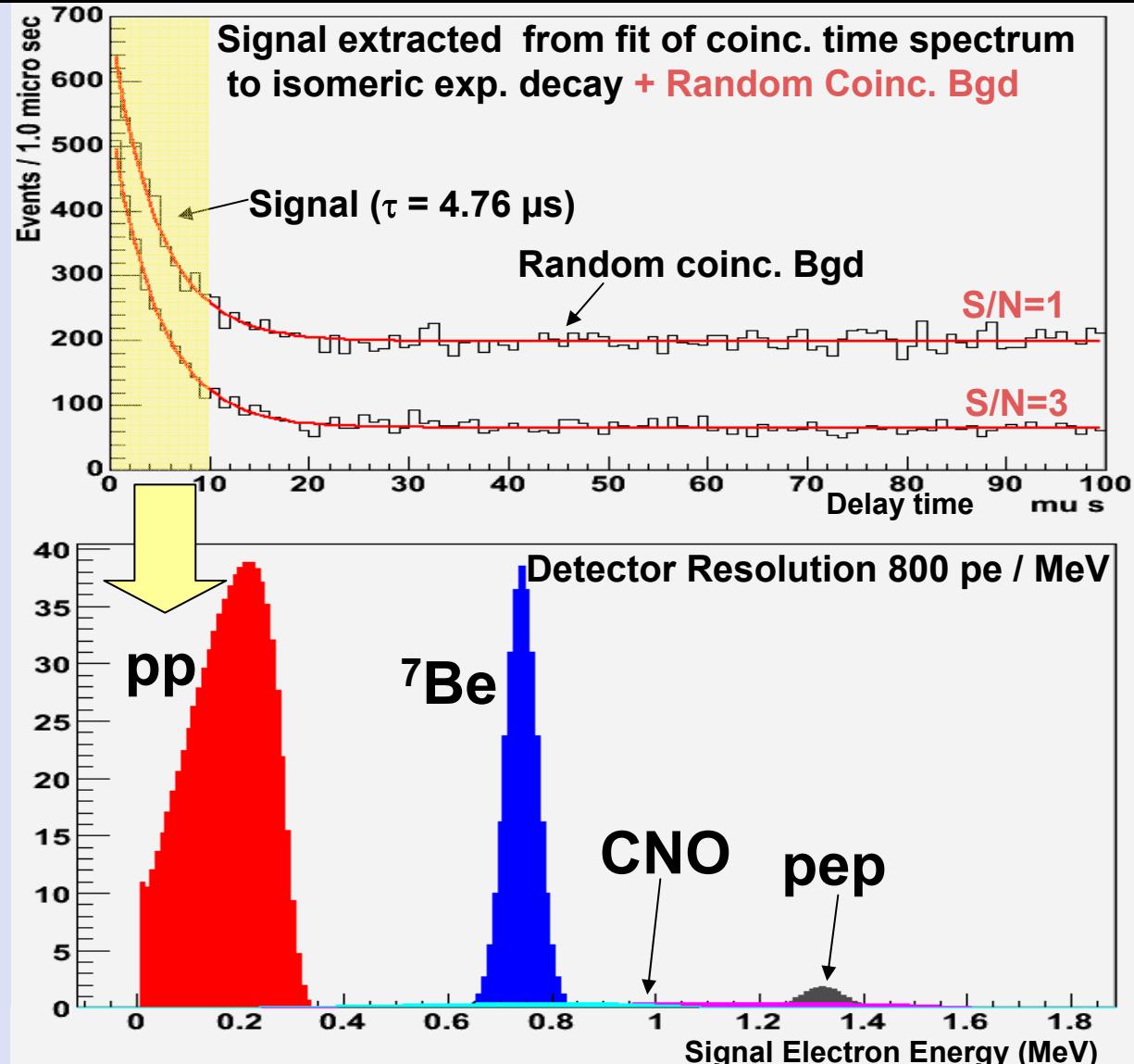
Expected Result: Low Energy Solar Neutrino Spectrum

LENS-Sol Signal
=
SSM(low CNO) + LMA
x
Detection Efficiency ϵ

pp: $\epsilon = 64\%$
 ^7Be : $\epsilon = 85\%$
pep: $\epsilon = 90\%$

→ Rate: pp $40 / \text{y} / \text{t In}$
→ 2000 pp ev. / 5y → $\pm 2.5\%$
→ Design Goal: S/N ≥ 3

Access to pp
spectral *Shape* for
the first time



NEW SCIENCE - Discovery Potential of LENS

APS Nu Study 2004 → Low Energy Solar Nu Spectrum: one of 3 Priorities

In the first 2 years (no calibration with ν -source needed):

- Test of MSW LMA physics - no specific physics proof yet !
 $P_{ee}(\text{pp})=0.6$ (vac. osc.) $P_{ee}(^8\text{B})=0.35$ (matter osc.), as predicted?
- Non-standard Fundamental Interactions?
Strong deviations from the LMA profile of $P_{ee}(E)$?
- Mass Varying Neutrinos?
(see above)
- CPT Invariance of Neutrinos?
so far LMA only from Kamland $\bar{\nu}_e$, is this true
also for ν_e ?
- RSFP/ Nu magnetic moments

Time Variation of pp and ${}^7\text{Be}$ signals? (No Var. of ${}^8\text{B}$ nus !)
(Chauhan et al JHEP 2005)

Low Energy
Neutrinos:
Only way to
answer these
questions !

NEW SCIENCE - Discovery Potential of LENS

In 5 years (with ν - source calibration):

- Absolute pp, ^7Be nu fluxes at earth $\pm 3\%$
- Measured Neutrino Luminosity ($\sim 4\%$)

Photon Luminosity \leftrightarrow Neutrino Luminosity
Ultimate test of the neutrino & the sun
Experimental status - No useful constraint!

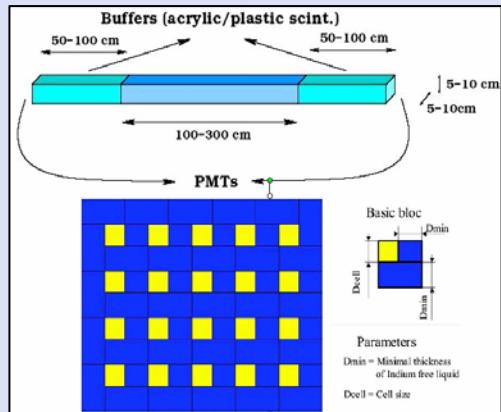
$$L_{\nu(\text{inferred})} / L_{h\nu} = 1.4 \begin{pmatrix} 0.2 \\ 0.3 \end{pmatrix}_{1\sigma} \begin{pmatrix} 0.7 \\ 0.6 \end{pmatrix}_{3\sigma}$$

- Test solar model and neutrino oscillations with one measurement
- Astrophysics: $L_\nu > L_{h\nu}$ Is the sun getting hotter?
 $L_\nu < L_{h\nu}$ Cooling or a sub-dominant non-nuclear source of energy in the sun?
- Precision values of θ_{12}, θ_{13} ; Sterile Neutrinos?

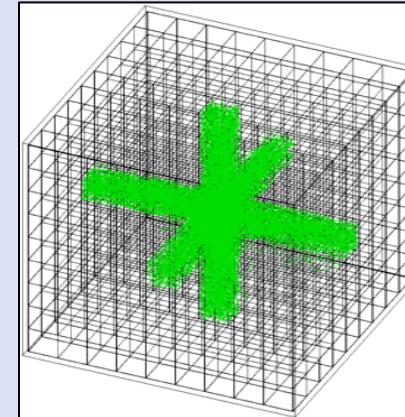
In-LENS: Studied Worldwide Since 1976!

Dramatic Progress in 2005

Status Fall 2003



Status Fall 2005



- In Liq. Scint.
- New Design
- Bgd Structure
- New Analysis Strategy

Longit. modules + hybrid (InLS + LS)

InLS: 5% In, $L(1/e)=1.5\text{m}$, 230 pe/MeV

Total mass LS: 6000t

In: 30t for 1900 pp ν's /5y

PMTs: ~200,000

pp-ν Detection Efficiency: ~20%

S/N~1 (single decay BS only)

~1/ 25 (All In decay modes)

(MPIK Talk at DPG 03/2004)

Cubic Lattice Non-hybrid (InLS only)

InLS: 8% In, $L(1/e)>10\text{m}$, 900 pe/MeV

Mass InLS : 125t to 190t

In: 10t-15t for 1970 pp ν's /5y

PMTs: 13,300 (3") - 6,500 (5")

pp-ν Detection Efficiency: 64-45%

S/N ~3 (ALL In decay modes)

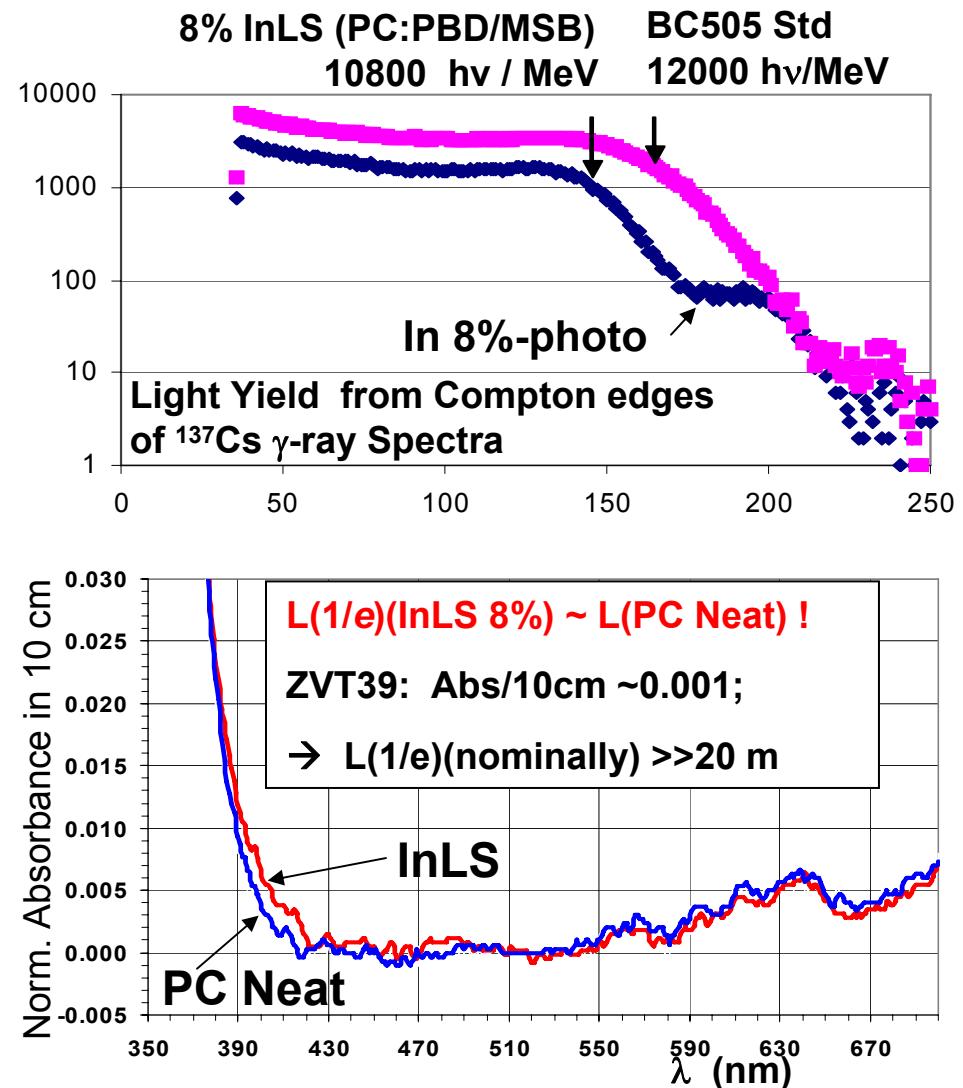
Indium Liquid Scintillator Status

Milestones unprecedented in metal LS technology

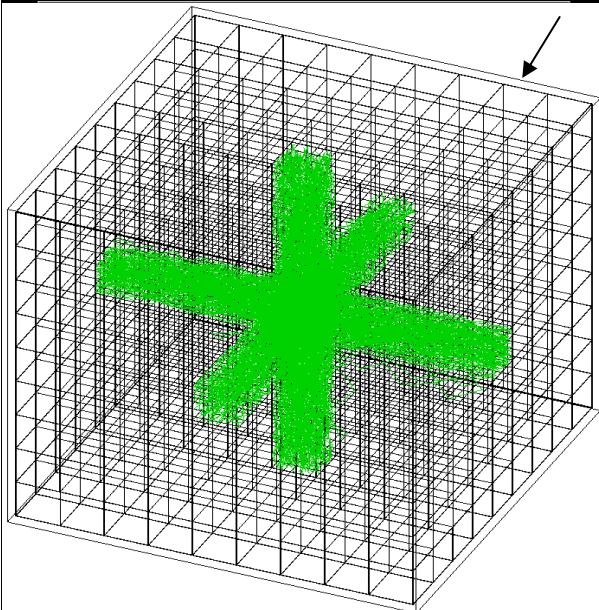
LS technique relevant to many other applications

1. Indium concentration ~8%wt (higher may be viable)
2. Scintillation signal efficiency (working value): 9000 $h\nu/\text{MeV}$
3. Transparency at 430 nm: $L(1/e)$ (working value): 10m
4. Chemical and Optical Stability: at least 2 years
5. InLS Chemistry - Robust

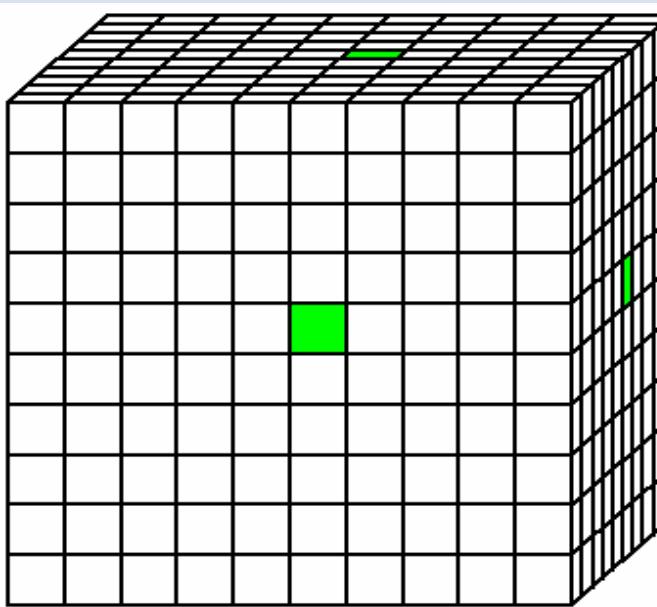
Basic Bell Labs Patent,
filed 2001, awarded 2004



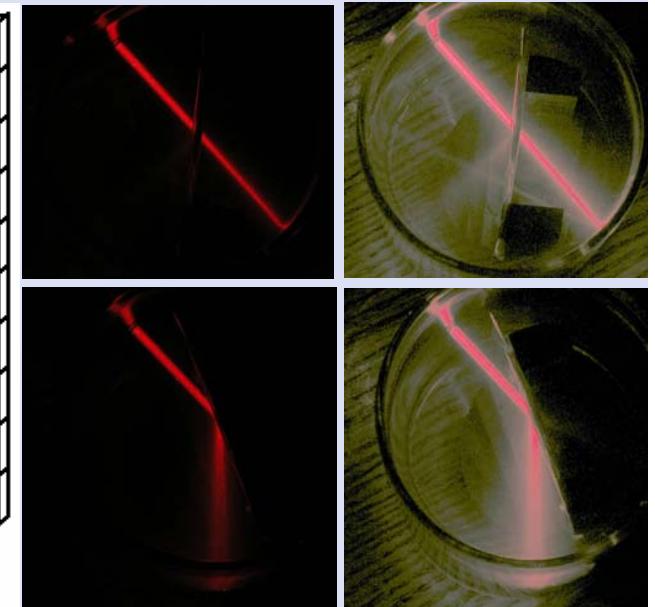
New Detector Concept - The Scintillation Lattice Chamber



Light propagation
in GEANT4



Concept

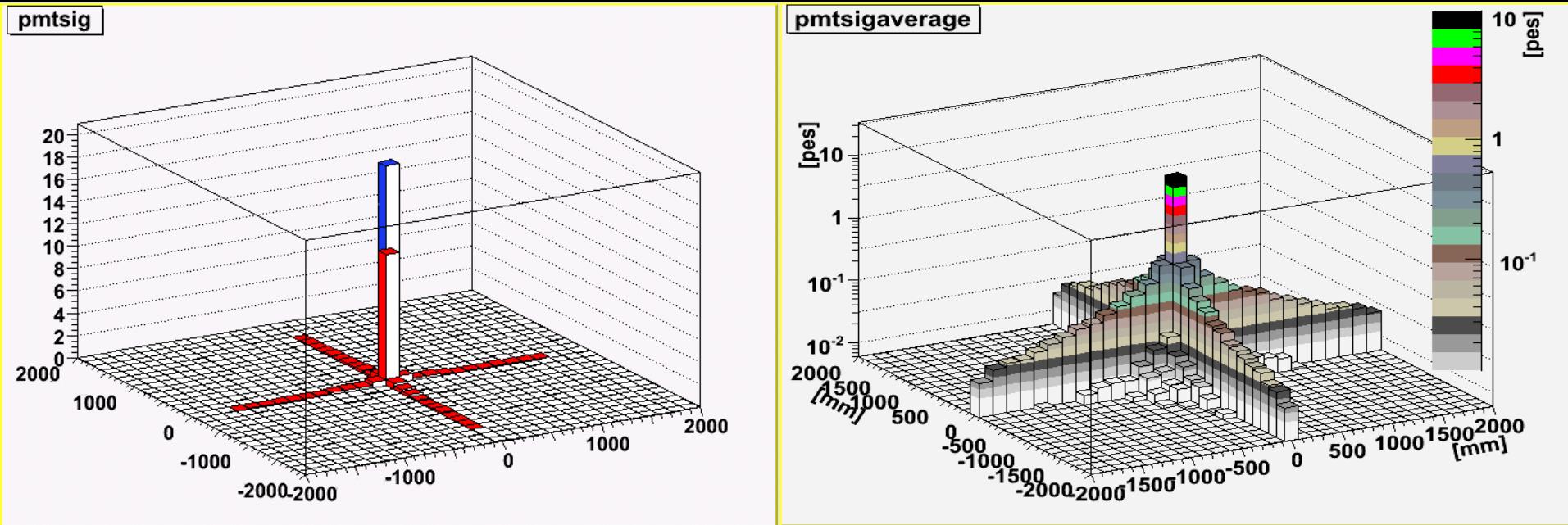


Test of double foil
mirror in liq. @~2bar

3D Digital Localizability of Hit within one cube

- ~75mm precision vs. 600 mm ($\pm 2\sigma$) by TOF in longitudinal modules
- x8 less vertex vol. → x8 less random coinc. → Big effect on Background
- Hit localizability independent of event energy

Foil Surface Roughness and Impact on the Hit Definition



100 keV event in 4x4x4m cube, 12.5cm cells

Perfect optical surfaces : 20 pe (per channel)

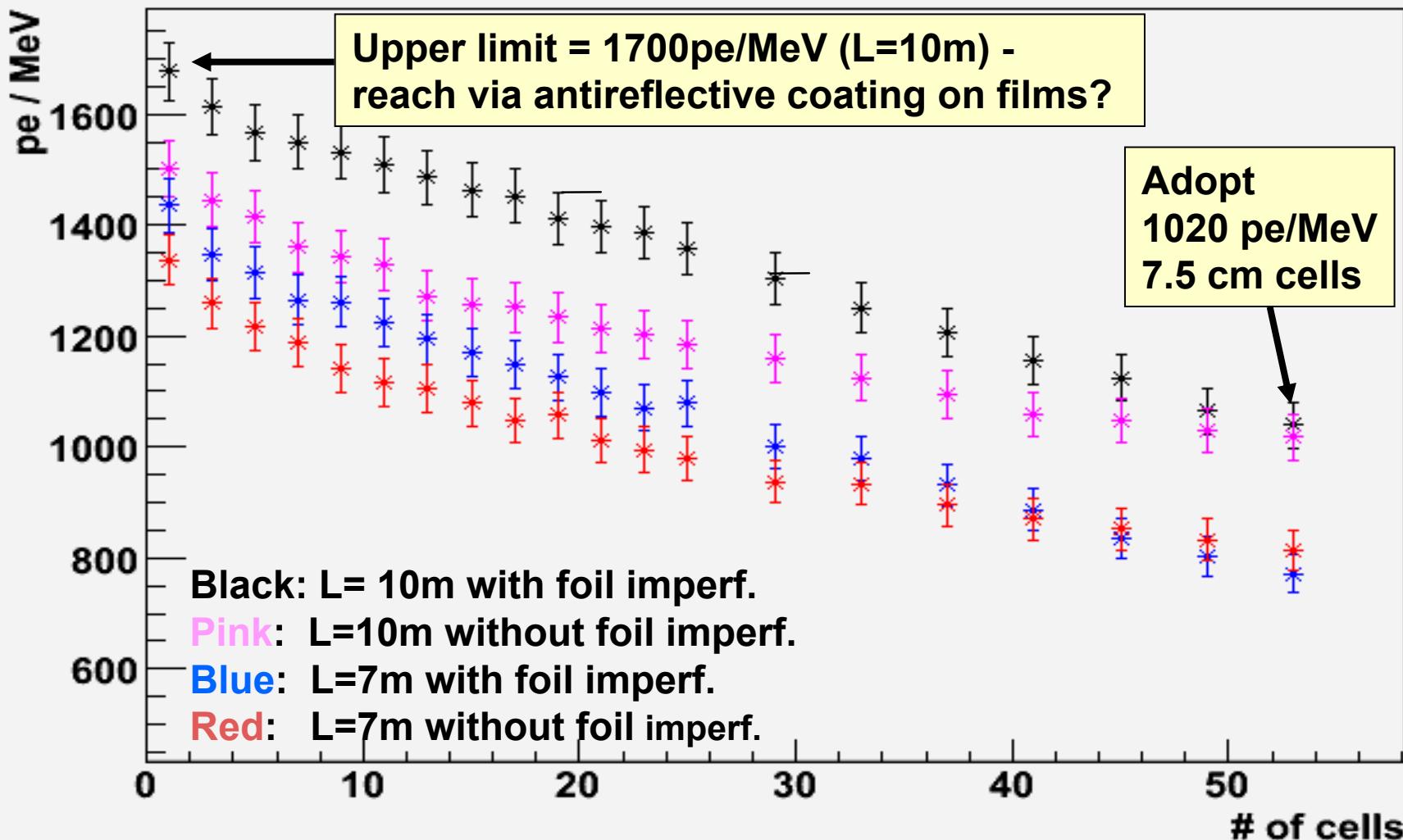
Rough optical surfaces : 20% chance of non-ideal optics at every reflection
12 pe in vertex + ~8 pe in “halo”

Conclusion - Effect of non-smooth segmentation foils:
No light loss - (All photons in hit *and* halo counted)
Hit localization accuracy virtually unaffected

Light loss by Multiple Fresnel Reflection

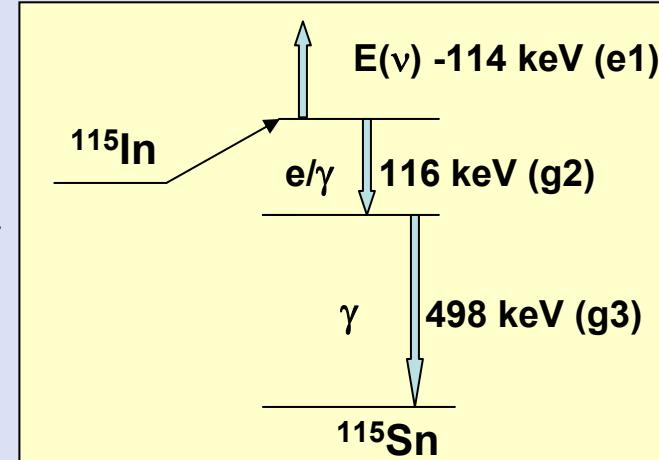
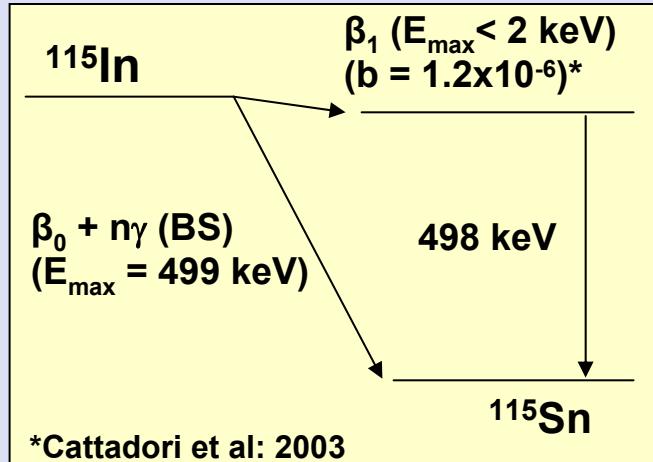
pe yield (400 cm detector)

4x4x4m Cube



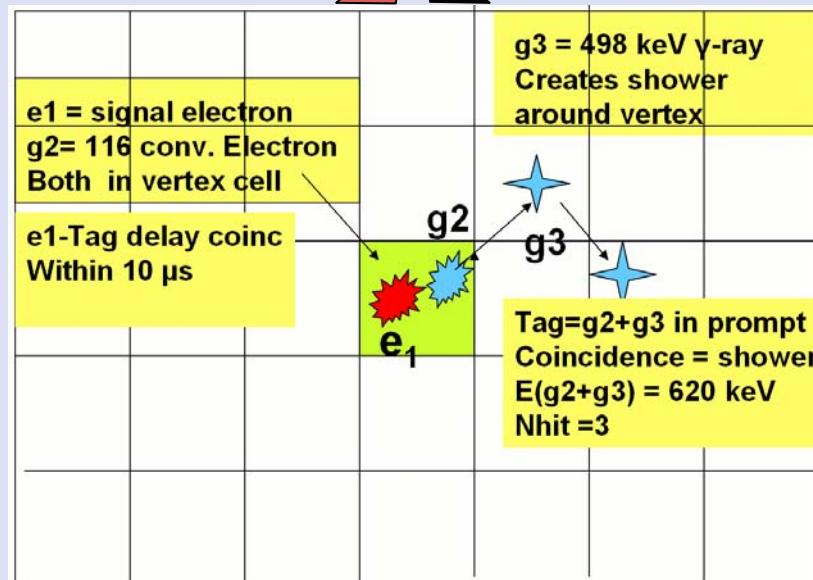
Indium Radioactivity Background

BGD



SIGNAL

Multiple ^{115}In decays simulate tag candidate in many ways



Indium Radioactivity Background

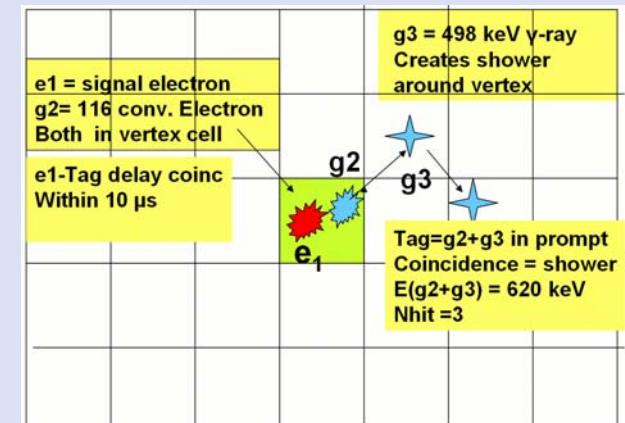
Background categories

n ^{115}In β -decays in (quasi) prompt coincidence produce a tag:

Basic tag candidate: Shower near vertex ($N_{\text{hit}} \geq 3$) - chance coincident with $^{115}\text{In} \beta$ in vertex

Type A: $A_1 = \beta + \text{BS } \gamma (E_{\text{tot}} = 498 \text{ keV}) \text{ (x1)}$ $A_2 = \gamma (498 \text{ keV}) \text{ (x1)}$ } Strong suppression via energy

Type B: 2 β -decays (x10⁻⁸)
Type C: 3 β -decays (x10⁻¹⁶)
Type D: 4 β -decays (x10⁻²⁴) } Suppression via tag topology



Indium Background Simulations and Analysis

Data: Main Simulation of Indium Events with GEANT4

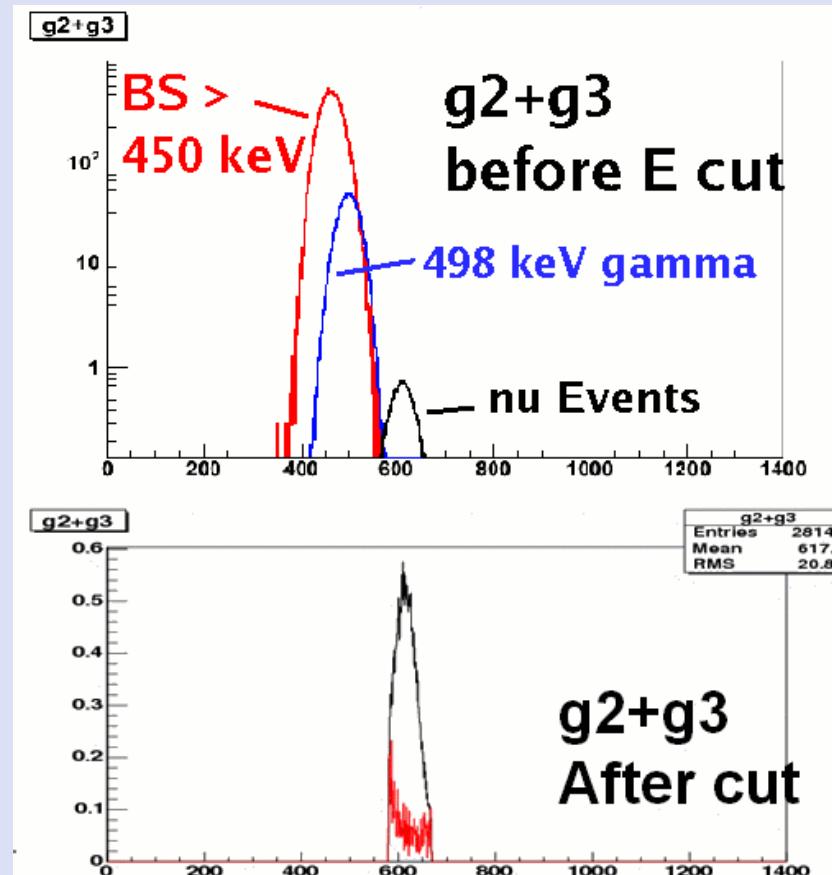
- $\sim 4 \times 10^6$ In decays in one cell centered in $\sim 3\text{m}^3$ volume (2-3 days PC time)
- Analysis trials with choice of pe/MeV and cut parameters (5' /trial)

Analysis Strategy

- Primary selection - tag candidate shower events with $N_{hit} \geq 3$
- Classify all eligible events ($N_{hit} \geq 3$) according to N_{hit}
- Optimize cut conditions *individually for each Nhit class*

Main Cuts

- Total energy: g_2+g_3
- Tag topology: Distance of lone β from shower



Background Suppression - Analysis of Tag Candidates

	Signal $/y /t \ln$	Bgd tot $/y /t \ln$	Bgd A1 $/y /t \ln$	Bgd A2 $/y /t \ln$	Bgd B $/y /t \ln$
RAW	62.5	79×10^{11}			
Valid tag (Energy, Branching, Shower) in Space/Time delayed coinc. with prompt event in vertex	50	"Free" 2.76×10^5	8.3×10^4	2.8×10^3	1.9×10^5
+ ≥ 3 Hits in tag shower	46	2.96×10^4	2.6×10^4	2.5×10^3	1.4×10^3
+ Tag Energy = 620 keV	44	306	0.57	4.5	293
+ Tag topology	40	13 ± 0.6	0.57	4.0	8.35

→ Tag analysis must suppress Background by $\sim 2 \times 10^4$

→ Sufficient to generate $\sim 4 \times 10^6$ n-tuples for the analysis

Final Result: Overall Background suppression $> 10^{11}$
At the cost of signal loss by a factor ~ 1.6

Typical LENS-Sol Design Figures of Merit – Work in Progress

Scintillator properties:

- InLS: 8% In
- $L(1/e) = 1000\text{cm}$
- $LY(\text{InLS}) = 9000 \text{ h}\nu/\text{MeV}$

Detector Design:

Cell Size mm	Cube size m	Pe yield /MeV	Det Eff %	pp- ν /t In/y	Bgd /t In/y	S/N	M (In)* ton	M (InLS) ton	PMT
75	4	1000	64%	40	13	3	10	125	13300 (3")
125	5	950	40%	26	9	2.9	15.3	190	6250 (5")

Summary

Major breakthroughs:

- In LS Technology
- Detector Design
- Background Analysis

→ Basic feasibility of In-LENS-Sol secure

- extraordinary suppression of In background
(all other Bgd sources not critical)
- Scintillation Chamber – InLS only
- High detection efficiency → low detector mass
- Good S/N



IN SIGHT: Simple Small LENS (~10 t In /125 t InLS)

Next Step

Test of all the concepts and the technology developed so far:

→ **MINI-LENS** - 200 liter InLS scintillation lattice detector

Additional Slides

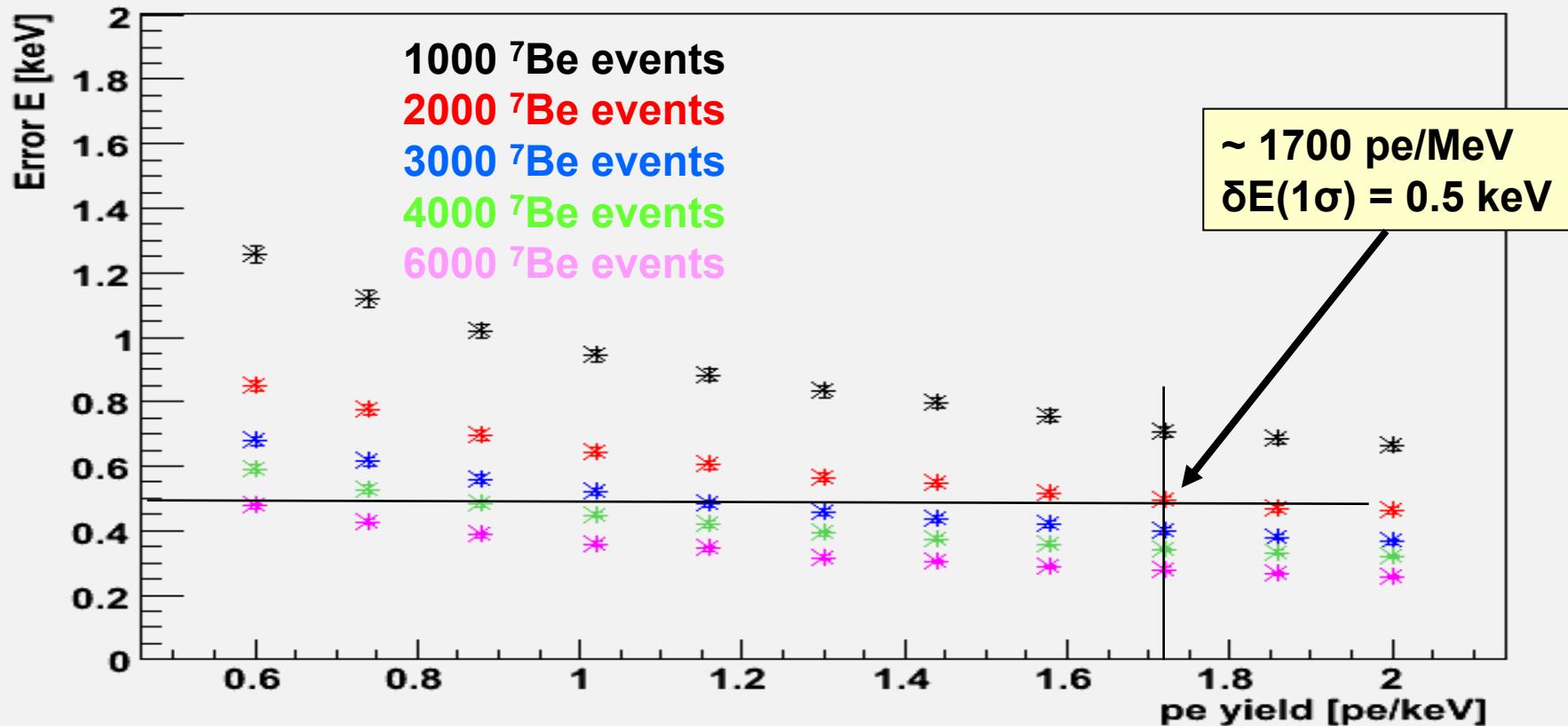
VT-NRL Low Bgd Laboratory @ Kimballton Limestone Mine VA

30 min by car from Virginia Tech



Direct Measurement of the Central Temperature of the Sun with High pe/MeV in LENS

Graph



Expected precision of centroid energy of ^7Be Line in LENS (*Statistics only*, 2000 events, 1700 pe/MeV): $\delta E(1\sigma) \pm 0.5 \text{ keV}$
Predicted solar shift (Bahcall 1993)) $\delta E = + 1.29 \text{ keV}$